The Scientific Basis for Timber Harvesting Practices[1]

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ABSTRACT

Silviculture, the applied ecology of forestry, is fundamentally a planned simulation of the seemingly destructive disturbances, small or large, gentle or severe, which have in nature created kinds of forest vegetation now regarded as desirable for human needs.

Silviculture is the part of forestry that is the applied science of growing stands of trees. Trees have to live outdoors through winter and summer, during dry years and wet, usually on poor land unsuitable for agriculture; society also prices wood and other benefits at a low rate; therefore, it has always been necessary for foresters to work very closely with rather than against natural processes. As a result, silviculture became a form of applied ecology even before the word was coined by a German scientist during the last century.

The basic objective of silviculture, in any given place, is to create a certain desirable kind of vegetational development. The fundamental analytical procedure is to determine the processes that created this in nature and then to simulate them directly or indirectly. The astonishingly paradoxical point of all this is that the ultimately constructive guiding force in replacing old with new or even with steering the development of established vegetation is lethally destructive disturbance.

It was said long ago and probably in a language other than English that the forest is built with the wise use of the axe, the same tool with which it can be witlessly destroyed. This remains at least figuratively true even though the number of lethal constructive weapons has increased. Fire (Fig. 1) and grazing animals probably came before the stone axe in human manipulation of forest vegetation.

Let me attempt to indicate to you why the silvicultural guidance of the establishment and growth of forests has to depend on the judicious killing of trees and other components of the vegetation. The killing may be of single individuals or of both large and small patches thereof. In a certain, somewhat academic sense, the question of whether the killing is or is not done by harvesting trees for useful products is rather incidental. The fact that this mode of tree killing can pay the costs and yield a profit is immensely advantageous; however, the wise long-term management of a picnic grove would necessitate killing some trees. We might well do it whether anyone ever used

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wood or not. If we can sell the wood, the net cost can be very substantially reduced.

Tree killing is the main silvicultural tool because forest vegetation typically fills all of the available growing space and cannot be changed or guided in its development without creating vacancies. Vegetation in general, and that of woody perennials in particular, hungrily expands its foliar cover and roots to fill all of the physiologically inhabitable space above and below ground. The occupancy soon becomes so complete that nothing new can be added unless some growing space is made vacant by killing something. In a more subtle way, the growth of one established plant can be enhanced by killing a competing neighbor. This kind of partial disturbance would merely speed natural development if the favored plant would have ultimately overgrown and shaded out the one that's artificially killed; however, if nature would have caused an opposite outcome, the partial disturbance could somewhat alter the course of development.

Any kind of vegetation tends to fill the growing space. With forests, it is simply more complete and more obvious. The phenomenon of the perennial woody stem is the most efficient terrestrial device for arranging energy-gathering foliage such that it is dispersed in depth in a transparent medium. Suspensions of floating algae waste little or nothing on supportive stems, but the medium is less translucent and there is no vertical conductive mechanism to take care of moving chemical nutrients upward. Water supply is something of a problem on land. In fact, forests with a closed foliar canopy exist only where there is plenty of water. Where water is in short supply but still sufficient for some trees to exist, their root systems often fill the whole soil stratum but the water that they pick up is sufficient to support only an incomplete foliar canopy.

I should underscore the point that the trees grow to fill the *available* growing space but not to use up all the growth-supporting factors. If they used all the growth factors, there would be no water left for stream flow; everything but the green light would be used and things beneath the forest would all look green. Absolute shortages of a given essential factor or seasonal shortages limit the capacity to use others. A phosphorus shortage might limit the amount of leafy photosynthetic apparatus and thus the amount of leaf tissue to transpire water; this would in turn release more water to stream flow. One manifestation of seasonal shortages with temporary surpluses is the development of understory vegetation with short annual cycles of active growth.

The beautiful spring flora of the eastern deciduous or hardwood forest is one of the classic manifestations of this; the spring flowers can burgeon to take advantage of heat, light, and water faster than the trees can. One might speculate that the microclimate near the ground beneath the cover of tree stems was less subject to frost than unshaded shoots at the top of the crown canopy. In any event, there is obviously a temporarily productive and reasonably secure niche at the forest floor in which the handsome plants can quickly grow and flower.

In silvicultural practice, we distinguish between two different kinds of lethal disturbance. Those intended to replace old stands with new ones are called regeneration cuttings; most of the rest of this talk will be about them. These cuttings have to be comparatively large in areal extent or at least large enough that new seedlings or small, young trees rather than old, adjacent ones fill the vacated growing space.

The other kinds of disturbance, traditionally called "intermediate cutting", are those in which scattered individual trees or, at most, offending vertical strata of trees, are removed or eliminated to favor other existing trees. Since cutting is not always involved, especially with modern development of tree-killing chemicals and more purposeful use of fire, the term "tending" is probably more appropriate. Anyhow, tending operations are aimed at guiding or accelerat-

Fig. 1.—Typical surface fire burning the grassy forest floor beneath a western ponderosa pine forest. This common natural phenomenon will kill some of the trees and pine seedlings will colonize the resulting vacancies. (U. S. Forest Service photo.)

ing development of established vegetation rather than its replacement. Such cuttings, "intermediate" in time between the regeneration cuttings, are almost always in the nature of partial removals.

Stands of forest trees can live so long and be so infrequently subjected to disturbance that it is hard to convince anyone that they are ever disturbed at all. Many forests owe their present characteristics to rare events which are not necessarily always destructive. The forst fire or windstorm of an hour's duration once every two or three centuries can govern the vegetational developments of the intervening time. In fact, it is either such events or attacks by fungal or insect pests which have been the initiating events of just about all of our natural forests. Most of the exceptions simply involve some less common kind of lethal disturbance such as landslides or volcanic eruptions.

The natural vegetation of any locality is a kind of repertory of species collectively adapted to fill virtually any kind of vacancy or new ecological niche that has come into existence as a result of natural disturbances (Fig. 2). There are plants that can claim the minimal growing space afforded by a rotten knot hole high up on a tree as well as lichens, algae, and mosses that colonize the surfaces of rocks and tree bark. Part of the solution to silvicultural regeneration problems is determining the kind of vacancy that favors the desired species (plural or singular) more than unwanted competitors.

It is not enough that they be able to get established; sooner or later, the desirable trees must be in an environment in which they can grow faster in height than the undesirable. Although one can strive to create the right conditions at the time new forest vegetation is established, some sort of corrective action is often necessary later on.

Some species are adapted to colonize severely exposed areas, especially those created by hot forest fires (Fig. 3). These species, aptly termed pioneers, can endure wide extremes of temperature and grow fast enough to push their roots

Fig. 2.—Newly germinated conifer seedling; survival at this stage depends on microclimatic factors which can be deliberately predetermined by cutting patterns. (U. S. Forest Service photo.)

quickly below the surface inch or two that is subject to severe desiccation. They must grow fast if they are to survive and require lots of light to support their rapid growth and high respiration rates. Among the natural fire-following species that fall in this category are jack and lodgepole pines as well as the aspen poplars and certain birches. In silvicultural practice, the regeneration of such species usually requires the complete removal of the old forest in clearcutting; however, certain other effects of the fires have to be simulated as well.

In a certain sense, fires kill forests from the bottom up because the heat is generated mainly by the burning of the litter of the forest floor. Some mineral soil may have to be exposed through such litter destruction if the seeds of the pioneers, which are often small and wind-dispersed, are to have satisfactory contact with the stable moisture supply of firm soil. It can also be very important to get the effect of killing of the subordinate vegetation which often includes tree species that started under the old stand but are not necessarily desirable or well-adapted to the soil conditions.

At the other extreme are the so-called shade-tolerant species that not only endure shade but also tend to require it in the early stages of development. These species have characteristics such as low respiration rates, high chlorophyll content, and efficient leaf arrangement that enable them to stay alive at low light intensity. Their seedlings do not grow rapidly in height simply because there has never been any survival value in doing so just as they have also sacrificed much ability to endure exposure.

These species include certain spruces, most true firs, hemlocks, and most maples and oaks. They are generally adapted to persist for many years beneath old stands of trees but to retain the capacity for initiating rapid height growth when released by lethal disturbances that kill forests from the top downward. The natural disturbances to which they are adapted are windstorms (Fig. 4), the lethal effects of defoliating insects, and fungi or other pests that weaken tree stems enough to cause them to break. Once these so-called "advance growth" species are established as seedlings or small saplings, it is possible to release them in any pattern of space and time that is appropriate for other management purposes; however, their regeneration fails if major removal cuttings take place

Fig. 3.—Very hot crown fire in western conifer stand. A new natural stand dominated by pioneer tree species would follow this severe disturbance. Clearcutting simulates this kind of disturbance but without certain baneful effects of such highly dangerous fires. (U. S. Forest Service photo.)

FIG. 4.—Severe blowdown in a west coast forest. If there is no subsequent fire (which would be very hot), the new forest will develop from advance growth already present or from progeny of the scattered remaining trees. (U. S. Forest Service photo.)

before the seedlings are adequately established.

As is usually the case in such matters, there are lots of species that represent adaptations to microenvironment that are intermediate between the extremes just described. Actually, there is a gradational series of adaptations from one end to the other. Many of our most important species fall into this broad intermediate category. They may individually have some special ecological requirements that must be met but they are generally flexible enough that a variety of regeneration cutting patterns and silvicultural techniques can be applied. Among the species in this group are Douglas-fir and such important pines as loblolly, slash, ponderosa, red, and the five-needled whites. In nature, most such species regenerated after fires that killed many trees but not all of them; however, it is not wise to generalize much about this point because windstorms and other kinds of disturbance were also commonly involved.

Much of what I have just said relates to the applied ecology of securing regeneration from seeds applied naturally or artificially out in the forest. While the silvicultural techniques that closely simulate nature often work and have such advantages as low out-of-pocket cost, it would be wrong to leave the impression that they always work or work well when they do. The numbers of seedlings are often either too many or too few, sometimes within the same acre. Furthermore, most trees do not bear seeds every year, nor does the rain always fall at the right time after the seeds fall.

The planting of nursery-grown seedlings is a way of by-passing many of these problems of timing and stand density. It is also coming to be increasingly prominent as a means of establishing stands of the progeny of selected trees.

There are considerations in addition to the ecological adaptations of young trees that govern the cutting patterns chosen to replace forests. All things have to be conducted in the context of economics, both that of the human needs of the next century and the frantic concerns of the present. The society of the day is concerned about its posterity but seldom to the extent of investing lavishly in it. A dollar spent on regeneration now is often required to hold promise of a return of $46.90 at 8% compound interest 50 years hence. Since society seems to expect wood to be cheap, harvesting costs are continually scrutinized and usually trimmed to the lowest level that law and prudence will allow.

Logging costs tend to weigh in favor of clearcutting in large units of area where the timber is large and on rugged terrain (Fig. 5). This is because ponderous machinery and expensive roads are required. The costs of roads and of moving in machinery are fixed costs and it is desirable to spread them over as much harvested product as possible.

If the terrain is easy and the trees smaller, the fixed costs are less significant, so more attention is paid to the variable costs. These are basically those of handling trees one by one and are inversely related to tree size. If it costs more to harvest a unit of produce from small trees than large, loggers would, if left to their own devices, cut only the larger ones.

It would be a remarkable coincidence if the short-term economic logic involved in minimizing the costs of one logging operation also optimized the long-term net benefit sought in managing a stand of trees through one rotation from birth to replacement. Some sort of compromise must be sought not only between long- and short-term financial considerations, but also among all the objectives and limiting factors involved in forest management.

One of the key decisions in forest management and silviculture involves the question of which parts of a whole forest should be composed of even-aged stands and which, if any, of uneven-aged stands. There are many factors which weigh in favor of having stands even-aged, or perhaps more precisely, more nearly even-aged than otherwise. The reasons why foresters the world over keep coming back to policies of even-aged manage-

Fig. 5.—Clearcut patches in Pacific Coast Douglas-fir; the nursery-grown seedlings that have been planted after the slash burning are too small to be visible. (Photo by author.)

ment are many and variable, although not of universal validity.

Before proceeding further, it is perhaps well to point out that even-aged management does not require clearcutting. The technique called shelterwood cutting, in which a new stand is started under an old one, is a method of even-aged management which becomes prominent when good forests have been developed (Fig. 6).

Matters of economy in administration, harvesting, and silvicultural treatment are certainly factors which favor even-aged management. It does help and save money to be able to conduct one kind of operation at a time over areas some acres in extent. It becomes both confusing and costly if one is simultaneously doing all things appropriate to all stages of stand age within a patch-work of sub-stands of differing age.

The alternative policy of uneven-aged management often requires that the entire road network of a forest be almost equally and continuously used. With even-aged management, operations are more concentrated in space, so parts of the road system can be left out of use for long periods. This not only saves money but reduces the amount of erosion-prone road surface; this is very crucial because nearly all of the soil and water damage that can be charged against timber-production forestry comes from roads.

Another common reason for even-aged management is simply that most stands are even-aged already and are difficult to change. In nature, many stands arise from the kinds of catastrophic disturbance that create even-aged stands. The very heavy cuttings, with or without ill-controlled fires, that characterized logging done without conscious intent of future management, often left even-aged stands. In fact, there are large areas of the country where the liquidation of old forests proceeded so rapidly that most of the stands are of nearly the same age; this creates a situation very difficult for securing the distribution of age classes necessary for sustained yield. It is not possible to change an existing pattern of age-class distribution in forests without replacing some trees prematurely or holding some beyond maturity.

Fig. 6.—Shelterwood cutting in Pacific Coast Douglas-fir with seedlings about 8 years old that naturally established themselves in the new environment created by heavy, partial cutting. (Photo by author.)

True uneven-aged management, in which distinctly different age classes are maintained within a stand, is appropriate to somewhat less common circumstances. The simplest are where there are already at least two immature age classes and it would be wasteful to liquidate them prematurely. The other is where there is some reason to want to have fairly large trees on the ground at all times. This is logical in certain recreation or scenic areas and where there is risk of land-slides. This kind of management is also useful on small holdings on which the growing timber is handled as a kind of fluctuating bank account with limited silvicultural investment.

Uneven-aged management or the so-called selection system of silviculture (Fig. 7) is very difficult to apply if the goal is to make each small stand a perfect, self-contained, sustained-yield unit. The methods for regulating harvests under

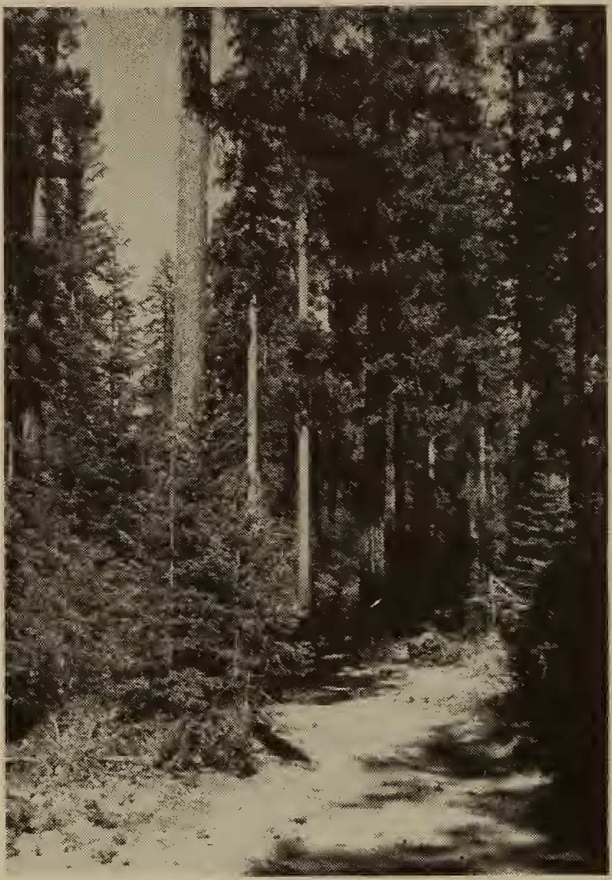

Fig. 7.—An uneven-aged stand of mixed conifers created by a series of selection cuttings conducted over a 30-year period along a scenic highway in a national forest near Crater Lake, Oregon. (Photo by author.)

such management are both complicated and highly unreliable. The advocates of the selection system and of uneven-aged management often destroy their case by doctrinaire insistence on making stands into sustained-yield units. There is plenty of room for incomplete applications of the selection system, but it is better to employ them only where real reasons exist for doing so and not merely because of whim or naturalistic mystique.

Nature can create large even-aged stands and also those with several irregularly distributed age-classes; however, the theoretical all-aged stand with all age-classes equally represented would be just as much of an artificial creation as a 1,000-acre plantation of loblolly pine, and so much harder to create that none are known to exist.

In considering some aspects of recent American silvicultural practice, it is necessary to point out that it is all still very new as far as the long time-scale of forestry is concerned. The whole idea of growing trees consciously really did not take hold to any significant extent in this country until the time of World War II. Most forestry on industrial holdings started about then. Before that time, most public forests were regarded as economically inaccessible so they were protected, but little was harvested from them.

Part of the reason why there is so much clearcutting now is that foresters of today have inherited a large backlog of stands in need of replacement. Some of these are the rather degraded kinds of vegetation left over from decades or from centuries of reckless cutting and inadequate protection. Others may be tottery old-growth stands that do not stand up well under partial cutting and consist largely of over-mature trees. Stands of this kind must generally either be reserved as museum pieces or replaced by clearcutting. It is very probable that there are lots of sites on which clearcutting will be a one-time-only operation as a stage-setting device and that subsequent stands will be handled by some variant of the shelterwood method. This method provides plenty of ways of getting the advantages of partial cutting under even-aged management, but it is hard to apply unless one has already created a good, vigorous and accessible forest.

Clearcutting is also involved in the quasi-agricultural kinds of silviculture aimed at intensive timber production. If thorough-going treatments with machinery or fire precede planting and if no reliance is placed on natural seeding, then it is expedient to employ clearcutting and planting. At present, one of the chief reasons for doing this is the attempt to establish genetically superior forests. This approach is especially fashionable on industrial holdings. Previous experience makes it logical to anticipate that it will work well with some species and on some soils, but that it will fall victim to insects, fungi, wind and other damaging agencies elsewhere. In some instances, the high expense will prove richly rewarding but in others there will be disappointment. The important thing is that this technique cannot be embraced as a universal solution nor condemned out of hand as a violation of nature; however, it does work best on somewhat dry sites where fire has been common in nature and has also produced rather simple stands of fast-growing pioneers.

There is no one best way of treating all forests; they are simply too variable in their natural behavior and in the socioeconomic circumstances that affect their management. The forests of this country are not only vast in extent but they include just about every kind of forest that might be found outside the tropics and even some of those. Furthermore, the silviculture that was best for the forest of a paper company on one side of a fence would differ from that of a bank teller on the other side.

The best decisions about silviculture practice are made by experienced, observant foresters on the ground who have the capacity, responsibility and authority for the necessary analytical thought. Attempts to dictate silvicultural decisions from distant points are inevitably based on sweeping, simplistic generalizations. Even if the prescriptions from distant sources fit 80% of the cases well, some disastrous failures can result from the 20% that do not fit. It matters not whether the distant source of authority is a legislature, the headquarters of either a government bureau or a corporation, or some university ivory-tower.

It has recently become fashionable to decry the techniques of silvicultural practice as a kind of ecological desecration. This is almost as far from the truth as one can get. Even the most artificial kind of forest must be quite close to a state of nature; if it isn't, it does not endure anyhow. It is logical to be concerned about the erosion which roads and other soil disturbance can induce. Much of this can be prevented. Nevertheless, it is perhaps often overlooked that the worst forestry causes far less erosion than the best of clean-cultivation agriculture. All living resources are renewable and there appear to be none more infinitely renewable than those of the forest. Furthermore, of all of the structural substances used by our civilization, there is none which can be produced and used with less input of energy than wood. Provided that efforts to clean up pollution from wood-pulp mills continue, it can also be said that none give less output of pollutants.

This country has a lion's share of the world's productive forest land. It is no recommendation for our past performance that we are net importers of timber and will probably remain so into the next century even if we start even greater intensification of forestry now. The question of whether we can put American forestry into the same key role as American agriculture depends on what is done in managing the myriad of small ownerships. These include not only the majority of the forest area but also a very high proportion of the most productive and accessible land. The contribution from public and industrial forests can certainly help, especially in the near term, but it cannot be enough to carry all the burden.

Our best hope for indefinite economic survival may lie in nuclear power; our surest hope is in protecting *and using* the productive capacity of our field and forest soil.

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